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Safety effects of an extensive black spot treatment programme in Flanders-Belgium

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ABSTRACT

Black spot management is a widely implemented measure to improve traffic safety. This study evaluates the safety effects of an extensive black spot programme that has been implemented in Flanders-Belgium. In total, around 800 black spots were selected, from which 134 locations, redesigned between 2004 and 2007, were included in this study. The adopted approach is an empirical Bayes before- and after study that accounts for effects of general trends and for the stochastic nature of crashes, including regression to the mean. Two different comparison groups were established. The analyses showed a decrease in the number of injury crashes of 24–27%, significant at the 1%-level. A separate analysis for crashes with serious or fatal injuries showed a decrease of 46–57%, also significant at the 1% level. The highest effects were found for the implementation of changes in the layout of priority controlled intersections and for the installation of traffic signals, which showed a decrease of respectively 42% and 35% in the number of injury crashes. Signalized intersections at which left-turn phasing was implemented resulted in a decrease of 22% in the number of injury crashes, changes in the layout leaded to a decrease of 11%. The conversion of intersections (both signalized and priority controlled) into roundabouts resulted in a decrease of 21% in injury crashes. The black spot programme generated a favourable effect on each of the road user categories (car occupants, moped riders, cyclists, motorcyclist, pedestrians and truck drivers).

1. Background

In an attempt to work to a better traffic safety, different countries introduced a black spot management (BITRE, 2012; Sørensen and Elvik, 2007). The term black spot refers to locations that have a higher expected number of crashes than other similar locations, as a result of local risk factors (Elvik, 2007). The purpose of a black spot programme is to reduce the number and severity of crashes, through infrastructural changes of these dangerous spots. In 2002 the Flemish Government decided to manage the most dangerous traffic spots as one of the main ways to reach the traffic safety goals. This programme included 809 black spots that were selected based on the number and the severity of the crashes. Ninety-nine percent were intersections, all located on highways. Every location at which at least three injury crashes occurred during the period 1997–1999 was selected, and a priority score was calculated. This score was based on the number of injured road users: every slightly injured person got a weight of 1, every severely injured person 3 and every fatally injured person 5. A total priority score of minimum 15 was necessary to be selected as a dangerous spot.

$$\text{Priority score} = 1 \times X + 3 \times Y + 5 \times Z$$

with X = number of slightly injured persons (any person who got injured, but cannot be defined as severely or fatally injured) Y = number of severely injured persons (any person who needed more than 24 h of hospitalization) Z = number of fatally injured persons (any person who died at the location of the crash or within 30 days after the crash).

The main research question in this paper is: what have been the effects of the Flemish black spot treatment programme on the number of crashes on the adapted sites?

2. Previous studies

Different previous studies examined the outcomes of black spot management in terms of the effect on crashes. Elvik et al. (2009) carried out a meta-analysis of studies that examined the traffic safety effect of black spot management trough a before- and after comparison of traffic crashes. They found that studies that did not controlled for regression to the mean (RTM) resulted in higher crash reductions than studies that did controlled for this confounding variable. As the selection of black spots is based on high crash

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counts, these locations are especially prone to RTM. For this reason Elvik et al. (2009) included only studies that controlled for this confounding variable. The authors found a decrease of 26% in the number of injury crashes as a result of black spot treatment. When only European studies were included, a decrease of 22% was found. A distinction between black spot treatment and black section treatment found a result that was somewhat greater for black spot treatment. The injury crashes on the latter decreased with 33%, whereas the crashes on black sections decreased with 28%. An extensive and recent Australian study (BITRE, 2012) examined 1599 black spot projects, which is 62% of the 2578 funded black spot projects approved and completed during the seven-year period from 1996–97 to 2002–03. This study showed a reduction of 30% in fatal and casualty crashes and 26% in property damage only crashes. Trend effects were controlled through inclusion of the total number of crashes in each state or territory. In order to control for RTM, pre-treatment crash data were selected during the interval of time between the date on which the funding application was submitted to the Australian Government and the date on which work on the project commenced.

3. Study design

The adopted approach is an empirical Bayes (EB) before- and after study. This is widely accepted as the best standard in the evaluation of traffic safety measures (Elvik, 2008; Elvik, 2012; Hauer, 1997; Persaud and Lyon, 2007). The method compares the observed number of crashes after the implementation of the treatment with the expected crash counts if there had been no treatment. This 'expected' number is based on the number of crashes before the treatment with correction for extraneous factors. Besides the effects of the treatment itself, a range of other factors has possibly had an effect on traffic safety and thus need to be corrected for. Those confounding factors are RTM, general crash trend, coincidence of the occurrence of crashes and general changes in traffic volumes (Elvik, 1997; Hauer, 1997). The chance effects were controlled through the use of point estimations and confidence intervals. According to Elvik (2002) traffic volumes do not need to be accounted for explicitly and it is sufficient to use a large comparison group, from which the total crash frequency encompasses several hundred. As the first comparison group comprised 211 locations, scattered around Flanders, and the second comparison group included all crashes in Flanders, this is sufficient to control for volume changes. Furthermore, it can be argued that the specific effect on traffic volumes due to the treatment of black spots most likely was very limited, because of the structure of the road system in Flanders. This structure does only give limited opportunity for drivers to choose alternative roads, as these mainly include local roads with lower speed limits. The treatment of black spots was mainly implemented at the upper category of roads, and therefore will probably have had a limited effect on the rerouting choices of the driver. To control for RTM and general trend effects the EB method was applied, as explained below.

4. Data

In order to make an analysis possible, a geographical localization of the crashes is necessary. At the time of the present study, localized crash data was available up to and including 2008. We considered it necessary to have available at least one year of crash data before and one year of data after the treatment of each black spot in order to make a before- and after evaluation possible. Subsequently, black spots treated and open for traffic up to and including 2007 could be evaluated, and a final research group of 134 black spots was selected. A graphical presentation of the selection process for the treated group and the comparison group is shown in Fig. 1.

The graph can be explained as follows: in total the Flemish government selected 809 black spots. On 160 of those 809 spots only small measures were planned, such as an alteration of the signal phasing or slightly changed markings. These locations were not selected, as no information was available about the date of those small changes, rendering it impossible to distinguish between the periods before and after the treatment. From the remaining 649 spots 201 were treated before 2008, which were selected as treated locations. After 2008, 294 locations remained to be treated, which as a result could be included in the comparison group. The latter locations are comparable with the locations in the treated group, but differ in that no treatment was applied yet. The other 154 locations could neither be included in the treated group, nor in the comparison group, as the infrastructural works had started before 2009 (and thus could not be selected for inclusion in the comparison group), but had not been finished yet until 2008 (and thus also could not be included in the treated group). This resulted in the inclusion of 201 locations in the treated group and 294 locations in the comparison group. For some locations traffic volume data was missing, which however was required to apply the EB approach. Subsequently, 69 locations from the treated group and 91 locations from the comparison group were excluded. Some black spots comprised two intersections, which were mainly intersections at the on- and off ramps of a highway. Since these locations were very close to each other, they were treated in the black spot programme as one location. However, in the present study each intersection was analyzed separately, and therefore the treated group had two locations extra and the comparison group eight locations. This eventually resulted in 134 treated locations; all being intersections. Depending on the location, different treatments were applied. Generally six sorts of treatments could be distinguished:

- signalized intersection → implementation of left-turn phasing: the majority of the treated locations (53) were signalized intersections on which protected left turns were implemented.
- Signalized intersection → changes in the layout: fifteen intersections that were signal controlled during the before period mainly got changes in the layout. Examples of alteration are: improved cycle facilities, separation of turning lanes and the installation of speed cameras.
- Signalized intersection → roundabout: five locations were changed from a signalized intersection into a roundabout.
- Priority controlled intersection → changes in the layout: of the locations that were priority controlled during the before period, 26 remained priorities controlled but changes were made in the layout. Examples of these changes are: provision of cycle facilities, improved delineation and construction of traffic islands or medians.
- Priority controlled intersection → signalized intersection: at nine locations that were previously priority controlled, traffic signals were installed, and six of them with protected left turns.
- Priority controlled intersection → roundabout: eight priority controlled locations were converted into a roundabout.

The final comparison group comprised 211 locations, all intersections. These locations can be expected to be comparable with the treated locations for certain characteristics (for example traffic volumes, maximum speed limit, . . .), whereas they differ in that there were no traffic safety measures implemented during the research period. As it is unclear whether or not a certain order in the treatment of black spots is present, and thus a certain distortion could be observed, a second comparison group was applied. This comprised all injury crashes in Flanders.

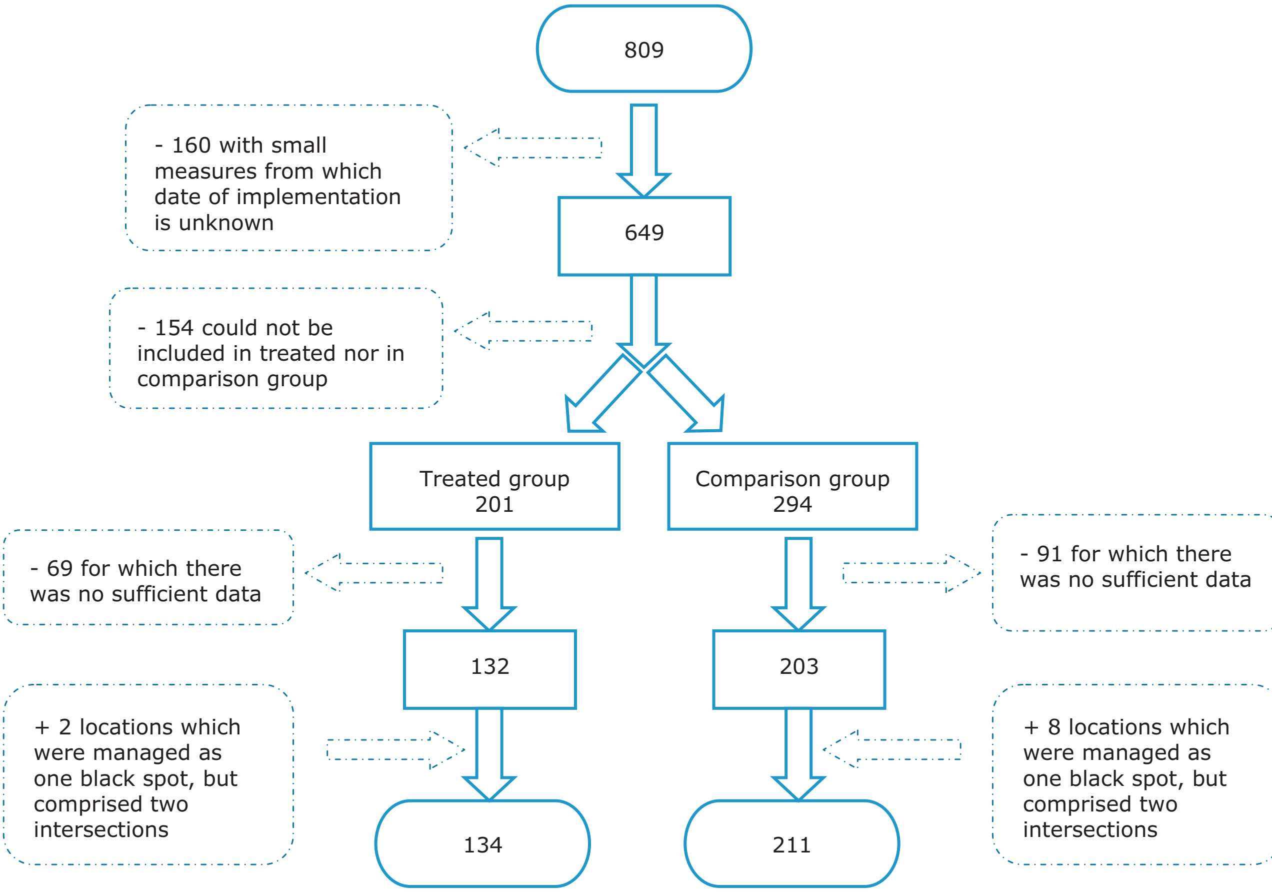

Fig. 1. Flow chart of the selection of treated and comparison locations.

All crashes in a radius of 100 m around the black spot were selected. Consequently, it can be expected that all crashes related to the black spot were included, also at the larger intersections and roundabouts. As the selection of the black spots was based on crash data from 1997 to 1999, these data were excluded from the research, in order to control for the RTM effect. Subsequently, the research period for this study ran from 2000 to 2008. Two groups of crash data were included: (1) all injury crashes; (2) severe injury crashes which included crashes with severely injured persons (every person that needed more than 24 h of hospitalization as a result of a crash) and fatalities.

The comparability of the comparison group with the treated group was analyzed through the odds ratios of the crash frequencies from the years of the before period. The applied odds ratio was the ratio of change in the crash numbers in the treated group, compared to the change in the comparison group. The odds ratio of two consecutive years can be expressed as:

$$\text{odds ratio} = \frac{R_t/R_{t-1}}{C_t/C_{t-1}} \quad (1)$$

with: R_t = the number of crashes in the treated group in year t, R_{t-1} = the number of crashes in the treated group in year $t-1$, C_t = the number of crashes in the comparison group in year t, C_{t-1} = the number of crashes in the comparison group in year $t-1$.

When groups are comparable, it can be expected that – in the period before the implementation of the measure – the relative crash evolution from year to year of the comparison locations will be similar to the evolution at the treated locations. The comparison group can be interpreted as comparable when this odds ratio is near to 1 (Hauer, 1997). The results of these calculations are shown in Table 1. As the first spots were treated in 2004, the odds ratio is calculated until that year. The calculations show that comparison group 1 (black spots treated after 2008) and comparison group 2 (all crashes in Flanders) are comparable with the treated group, both for all injury crashes, as for the more severe crashes.

Table 1
Odds ratios of the crash numbers during the before period.

	Comparison group 1		Comparison group 2	
	All injury crashes	Severe crashes	All injury crashes	Severe crashes
00–01	1.02	0.92	0.95	0.86
01–02	1.04	1.14	1.11	0.93
02–03	1.14	1.13	0.94	0.90
Average	1.07	1.06	1.00	0.90

Furthermore, the qualitative characteristics of comparison group 1 were compared with the treated group. The following equation is used to examine this:

$$\frac{\text{number of locations in research group with a certain charateristic/total number of locations in research group}}{\text{number of locations in comparison group with a certain characterstic/total number of locations in comparison group}} \quad (2)$$

Four characteristics were compared, that is location inside/outside the urban area, the type of intersection during the before period (priority controlled or signalized), and the legally imposed speed limit and number of lanes on the main and secondary road of the intersection. No strong differences were found. Only intersections with a speed limit of 90 km/h on the main road

were significantly more present in the treated group compared to the comparison group (Fisher's exact test: 1.53 $p = 0.041$). From these analyses it can be concluded that both comparison groups are comparable with the treated group.

5. Method

5.1. Analysis per location

The analysis per location can be expressed through an odds ratio, which results in an estimation of the index of effectiveness (θ_l):

$$\theta_1 = \frac{L_1/E[\kappa|K]_1}{N/M} \quad (3)$$

$E[\kappa|K]_l$ = estimated number of crashes at the treated location L in the before period L_l = observed number of crashes at the treated location L in the after period M = observed number of crashes in the comparison group in the before period N = observed number of crashes in the comparison group in the after period.

In order to increase the precision of the estimates the crash counts of the treated location and the crash frequency expected at similar entities are used (Hauer et al., 2002):

$$E[k|K]_l = w \times E[\kappa] + (1-w) \times K_l \quad (4)$$

where $E[\kappa|K]_l$ = expected number of crashes at the treated location L given the observed crash frequency K_l, w = the weight (between 0 and 1) that is given to the crashes at similar entities $E[\kappa]$ = average number of crashes at similar entities, $1-w$ = the weight that is given to the crashes at the treated location L, K_l = observed number of crashes at the treated location L.

To calculate the average number of crashes at similar entities ($E[\kappa]$), a safety performance function (SPF) is used that has been developed based on the current dataset that included both treated and comparison locations (De Ceunynck et al., 2012). The dependent value of the model was the number of crashes that occurred during the period 2000–2003. This period was selected in such a way that it was not subject to the effect of RTM (as it was after the period that was used to select the black spots, i.e.1997–1999) and furthermore this period clearly reflects the before period as the first locations were only changed in 2004. In a first model estimation traffic volumes at the major and minor road of the intersection and the traffic control variable (priority controlled vs. signalized intersections) were included as independent variables, however the latter variable was found to be insignificant. The model that was applied in the present research estimates the number of injury crashes and severe crashes through traffic volumes:

$$E_{\text{injury}}(\lambda) = e^{-1.7131} Q_{\text{Maj}}^{0.3231} Q_{\text{Min}}^{0.2463} \quad (5)$$

$$E_{\text{severe}}(\lambda) = e^{-3.2138} Q_{\text{Maj}}^{0.3327} Q_{\text{Min}}^{0.2009} \quad (6)$$

with $E(\lambda)$ = expected annual number of crashes (dependent variable), with E_{injury} are all injury crashes, and E_{severe} are severe and fatal injury crashes, Q_{maj} = traffic volume on the major road of the intersection (min: 26 vehicles/h; max: 5840 vehicles/h; mean: 1508 vehicles/h; med: 1378 vehicles/h). Q_{min} = traffic volume on the minor road of the intersection (min: 4 vehicles/h; max: 3424 vehicles/h; mean: 537 vehicles/ho; med: 383 vehicles/h).

Table 2 gives more information on each of the models. The weight (w) can be calculated through the following equation:

$$w = \frac{E[\kappa]}{E[\kappa] + \text{Var}[\kappa]} = \frac{1}{1 + \left(\text{Var}[\kappa]/E[\kappa]\right)} \quad (7)$$

with Var[κ] is the variation around $E[\kappa]$.

The next step is to control for general trend effects. Trend effects are controlled through the inclusion of the crash frequencies of the comparison group. Two comparison groups were used: (1) black spots modified after the study period; (2) all injury crashes in Flanders. Consequently the value of θ_l (see Eq. (3)) can be calculated. This value reflects the estimate of the impact of the black spot programme. As θ_l has a lognormal distribution (Fleiss, 1981), the variance s_l^2 of $\ln(\theta_l)$, which is the natural logarithm of θ_l, can be calculated as:

Table 2
Dispersion and criteria for goodness of fit of the SPFs.

	Injury crashes	Severe crashes
Over dispersion parameter	0.2635	0.2026
Deviance	516.57	540.94
Pearson chi-square	576.43	483.05
Log likelihood	9396.60	−187.61

$$s_1^2 = \frac{1}{L_1} + \frac{1}{E[\kappa|K]_1} + \frac{1}{N} + \frac{1}{M} \quad (8)$$

And a 99% confidence interval (CI):

$$\theta_{1,\text{belowlimit}} = \exp[\ln(\theta_1) - 2.58 \times s]$$
$$\theta_{1,\text{abovelimit}} = \exp[\ln(\theta_1) + 2.58 \times s] \quad (9)$$

5.2. EB estimates for the after period

Although such is rarely done, an EB-approach is also justified for the estimates in the after period as it increases the precision of the resulting estimates (Hauer et al., 2002). This is particularly true when only one or two years of crash data are available. Moreover there is a chance that, especially for the severe crashes, the observed number of crashes at a treated location in the after period equals zero. In this case it is impossible to calculate the variance (see(8)) and the index of effectiveness (see (3)). Also intuitively, the presence of a zero level of crashes is not very likely to be a correct long term average as it would be equal to a 'perfect' safety. This problem was solved through the calculation of a model for the after period. The model was based on the abovementioned data (see (5)) and fit to the crash data of the treated locations in the after period. The analyses resulted in the following equation, valid for the group of injury crashes (over dispersion = 0.0752; deviance = 140.52; Pearson Chi-square = 135.19; log likelihood: −72.33):

$$E_{\text{injury}} = e^{-6,1395} Q_{\text{Maj}}^{0.55} Q_{\text{Min}}^{0.345} \quad (10)$$

A similar model for the severe crashes could not be fit, as the convergence was questionable, which was probably due to a very low sample mean and a too high number of zero crashes. Therefore the model of all injury crashes was applied and it was multiplied with the proportion of the severe crash numbers to all injury crash numbers from the after period. Subsequently, estimates for the safety level in the after period for each location were calculated by applying Eqs. (4) and (7).

5.3. Meta-analysis

The evaluation of each location separately has only limited significance. Therefore a fixed effects meta-analysis was carried out, which results in one overall effect estimate and in more statistically reliable outcomes (Fleiss, 1981). Every location within the meta-analysis gets a weight, which is the inverted value of the variance. Subsequently locations at which many crashes occurred, are given a higher weight.

$$w_1 = \frac{1}{S_1^2} \quad (11)$$

Table 3
Results of the meta-analyses (index of effectiveness [99% CI]).

	Injury crashes	Severe crashes
Comparison group 1 (black spots treated after 2008)	0.76 [0.66; 0.87][a]	0.54 [0.36; 0.81][a]
Comparison group 2 (all injury crashes in Flanders)	0.73 [0.64; 0.84][a]	0.43 [0.28; 0.64][a]

[a] Significant at the 1% level.

Supposing that the measure is executed at n different places, the weighted mean index of effectiveness of the measure over all places θ is:

$$\theta = \exp\left[\frac{\sum_{l=1}^{n} w_1 \times \ln(\theta_1)}{\sum_{l=1}^{n} w_1}\right] \qquad (12)$$

The estimation of a 99% CI is

$$\theta_{\text{below limit}} = \exp\left[\frac{\sum_{l=1}^{n} w_1 \times \ln(\theta_1)}{\sum_{l=1}^{n} w_1} - 2.58 \times \frac{1}{\sqrt{\sum_{l=1}^{n} w_1}}\right] \qquad (13)$$

$$\theta_{\text{above limit}} = \exp\left[\frac{\sum_{l=1}^{n} w_1 \times \ln(\theta_1)}{\sum_{l=1}^{n} w_1} + 2.58 \times \frac{1}{\sqrt{\sum_{l=1}^{n} w_1}}\right] \qquad (14)$$

6. Results

A meta-analysis of the 134 black spots, using comparison group 1 (i.e. black spots treated after 2008) to control for the trend, showed a decrease in the number of injury crashes of 24%, which was significant at the 1% level (see Table 3). A decrease of 27% was found, also significant at the 1% level, when trend was controlled through comparison group 2 (i.e. the total number of crashes in Flanders). In the case of the fatal and serious injury crashes, significant decreases at the 1% level were found. This decrease amounted 46% and 57% when respectively comparison group 1 and comparison group 2 were used.

In addition to the overall effect, the effects were analyzed according to the characteristics of the locations. Five characteristics were analyzed: (1) location inside/outside the urban area, (2) type of intersection during the before period, (3) type of treatment, (4) number of lanes at the main road and (5) maximum speed limit at the main road. The road with the highest road category was selected as the main road. When several roads had the same road category, the roads were ordered according to the traffic volume. These analyses were applied on injury crashes and comparison group 1 was used in order to control for trend effects.

As can be seen from Table 4, slightly higher effects were found for locations outside the urban area (−29% vs. −19%). No large differences were found according to the number of lanes and the maximum speed limit. The meta-analyses, according to the type of intersection during the before period, showed higher effects for intersections that were previously priority controlled (−33%) compared to signalized intersections (−21%). A comparison of the effect according to the type of treatment showed the highest effects for priority controlled intersections at which the layout was changed (−42%). Furthermore, also high decreases were found for intersections with new traffic signals (−35%). The implementation of left-turn phasing at signalized intersections resulted in a decrease of 22%. Changes in the layout at signalized intersections resulted in a decrease of 11% in the number of injury crashes. The conversion to roundabouts showed a decrease of 21%. A different effect was found according to the type of intersection before the conversion: signalized intersections that were converted to a roundabout showed a decrease of 28%, whereas a decrease of 13% was found for locations that were previously priority controlled.

In order to analyze whether the differences were statistically significant, maximum likelihood linear regression models (using SPSS GENLIN procedure) were fitted. The dependent variable was the natural logarithm of the effect per intersection $\ln(\theta_1)$. The five characteristics as shown in Table 4 were the independent variables, which were dummy-coded. Two extra variables were included: (6) priority score (which indicates the number and severity of injuries during 1997–1999) and (7) traffic volume at the main road. In the dummy coding of the type of treatment, the reference variable was ‘changes in the layout of priority controlled intersections’. This resulted in four parameters: roundabout vs. changes in the layout of priority controlled intersections; protected left-turn signals vs. changes in the layout of priority controlled intersections; changes in the layout of signalized intersections vs. changes in the layout of priority controlled intersections; installation of traffic signals vs. changes in the layout of priority controlled intersections. In a first regression analysis a high correlation ($\rho > 0.60$) was found between the type of intersection during the before period and two parameters of the type of treatment variable: ‘protected left-turn signals vs. changes in the layout of priority controlled intersections’ ($\rho = -0.74$) and ‘changes in the layout of signalized

Table 4
Results of the meta-analyses (index of effectiveness [95% CI]) subdivided to the characteristics of the location.

Characteristics	Categories	No. of locations	Index of effectiveness [95% CI]
Inside/outside urban area	Inside	37	0.81 [0.66; 0.98][a]
	Outside	86	0.71 [0.63; 0.81][a]
Number of lanes	2	68	0.71 [0.60; 0.85][a]
	4	64	0.79 [0.69; 0.90][a]
Maximum speed limit	50	29	0.79 [0.63; 0.98][a]
	70	39	0.73 [0.60; 0.89][a]
	90	62	0.77 [0.66; 0.89][a]
Type of intersection before	Priority controlled	55	0.67 [0.55; 0.82][a]
	Signalized	74	0.79 [0.70; 0.90][a]
Type of treatment	Roundabout ←Signalized ←Priority controlled	1558	0.79 [0.53; 1.18]0.72 [0.38; 1.36]0.87 [0.49; 1.57]
	Installation of traffic signals	9	0.65 [0.43; 0.99][a]
	Changes in layout of priority controlled intersection	26	0.58 [0.42; 0.80][a]
	Changes in layout of signalized intersections	15	0.89 [0.66; 1.19]
	Implementation of left-turn phasing at signalized intersections	53	0.78 [0.67; 0.89][a]

[a] Significant at the 5% level.

Table 5
Results of the regression analysis.

Parameter	Parameter estimate	Standard error	Chi-square	Sig.
Intercept	−0.44	0.14	10.37	0.001
4 vs. 2 lanes (main road)	−0.09	0.12	0.53	0.47
50 km/h vs. 90 km/h (main road)	−0.05	0.11	0.17	0.68
70 km/h vs. 90 km/h (main road)	−0.15	0.09	2.77	0.10
New traffic signals vs. changes layout priority controlled	0.05	0.15	0.10	0.75
Protected left-turn signals vs. changes layout priority controlled	0.27	0.13	4.55	0.03[a]
Changes layout signalized vs. changes layout priority controlled	0.47	0.14	12.32	<0.001[b]
Roundabout vs. changes layout priority controlled	0.55	0.15	12.91	<0.001[b]
Priority score	−0.01	0.003	14.69	<0.001[b]
Traffic volume (ADT[a] 1000)	0.10	0.03	9.15	0.002[b]

Deviance: 16.31; df: 99.
[a] Significant at the 5% level.
[b] Significant at the 1% level.

intersections vs. changes in the layout of priority controlled intersections' ($\rho = -0.77$). The variable with the smallest contribution to the model fit was eliminated, which was the type of intersection during the before period. A new model was fitted, which again showed a high correlation between two variables: speed limit (50 km/h vs. 90 km/h) and location inside/outside the urban area ($\rho = -0.70$). The location inside/outside the urban area was the variable with the smallest contribution to the model and was excluded. The results of the model without these variables are shown in Table 5. Five significant parameters were found. The parameters with the type of treatment showed three significant results. Changes in the layout of priority controlled intersections performed significantly ($p < 0.05$) better compared to:

- the implementation of protected left-turn signals at signalized intersections (parameter estimate: 0.27).
- Changes in the layout of signalized intersections (parameter estimate: 0.47).
- Conversion to roundabouts (parameter estimate: 0.55).

Fourth, the priority score was a significant predictor. The sign of the revealed effect is negative, meaning that higher effects were found as the priority score increases (parameter estimate: −0.01). Furthermore, the effect of the traffic volume was found to be significant. The results showed lower effects as the volume increases (parameter estimate: 0.10).

In addition to the analyses on crash level, analyses on the level of casualties were performed. The effect on the number of injured road users was analyzed, subdivided to the type of road user: car occupants, moped riders, cyclists, motorcyclists, pedestrians and truck drivers. A before- and after-comparison was performed with control for trend effects through comparison group 1 (i.e. the black spot comparison group). As the relative differences from the before to the after period in Table 6 show, higher decreases were found for the treated group compared to the comparison group. This is confirmed by the relative change, which is the odds ratio of the change in crashes from the before to the after period in the treated group with the change in crashes from the before to the after period in the comparison group. As the rightmost column shows, all of these results are smaller than one. From this can be concluded that the black spot programme generated a favourable effect on each of the road user categories.

7. Discussion

In order to control for trend effects, two comparison groups were used. The first group included the black spots that were treated after the research period, which can be expected to be similar with the treated locations but at which no treatments were applied yet. As it is unclear whether or not a certain order in the treatment of black spots is present, and thus a certain distortion could be observed, a second comparison group was applied which comprised all crashes that occurred in Flanders. A possible limitation of the comparison group that comprised all crashes in Flanders is that the crashes that occurred at the treated locations were also included in the comparison group. This could lead to an underestimation of the effect, as the result of the black spot programme is included in the general trend. However, only 1.1% of all crashes in Flanders occurred on the treated locations. In addition, the results of the analyses using this comparison group were in line with the results of the analyses that used the other comparison group, and were even higher.

The results of the analyses indicated that the treatment of the black spots had a favourable effect on traffic safety. However, the treated group only encompassed 134 of the 809 black spots, from

Table 6
The effect on injured road users.

Type of road user	Mean number of injured road users per year per black spot						Odds ratio
	Treated group			Comparison group (black spots treated after 2008)			
	Before	After	Difference (%)	Before	After	Difference (%)	
Car occupants	2.19	1.07	−50.90	1.95	1.59	−18.55	0.60
Moped riders	0.30	0.19	−36.43	0.40	0.29	−26.71	0.87
Cyclists	0.41	0.29	−29.59	0.45	0.45	2.16	0.69
Motorcyclists	0.16	0.10	−39.55	0.15	0.13	−10.64	0.68
Pedestrians	0.07	0.05	−27.20	0.09	0.08	−18.44	0.89
Truck drivers	0.05	0.01	−77.63	0.05	0.04	−21.33	0.28

which can be questioned whether these results can be generalized to all black spots in Flanders. At 160 locations only some small changes were implemented. The treated group was not selected randomly from the remaining 649 locations, but the selection was more or less based on the year the black spot was treated, as only the spots were selected that were treated before 2008. When a certain pattern was present in the order of the treatment, the 134 black spots could be different from the other 515 locations. However, an analysis of the comparability of the treated group and the comparison group that comprised black spots treated after 2008, showed no structural differences between both groups. From this can be concluded that the results of the present paper are a good estimation of the total black spot programme in Flanders. Nevertheless, a new evaluation when the entire programme will be finished could provide extra information, as a lot more locations would be included.

In the present study no distinction was made according to the crash type. It could for example have been interesting to analyze what effects the installation of new traffic signals and of protected left-turn signals had on side crashes on the one hand and on rear-end crashes on the other hand. However, this subdivision into different crash types would lead to a low number of crashes, from which it is difficult to make any valid analyses. The study for example included 9 locations at which traffic signals were installed, with in total 2.79 crashes/year during the before period and 1.47 crashes/year during the after period. This number is too small to make any further classification. It would however be interesting to analyze this in future research when more locations are treated.

Despite these limitations we can conclude that the treatment of black spots is an effective traffic safety measure. The meta-analyses showed a significant decrease both for the injury crashes and for the severe crashes. In the case of the injury crashes a decrease of 24–27% was found. The number of fatal and serious injury crashes decreased with 46–57%. These are significant and meaningful results, which are in line with previous results. Through the inclusion of different before- and after studies that controlled for RTM, Elvik et al. (2009) found a decrease in the number of injury crashes of 26%. However, when only black spots and no black sections were taken into account, the study found a decrease in the number of injury crashes of 33%, which is slightly higher than what was found in the present study. The effect on the severe crashes cannot be compared, as most studies only analyzed the effect on the total number of injury crashes. Nevertheless, it can be concluded that the decrease in the number of severe crashes (−46% and −57%) is significantly greater compared to the decrease in the number of all injury crashes (−24% and −27%). A paired sample *t*-test (SPSS20) showed a statistical significant difference between the effect on all injury crashes and the effect on the severe crashes, both for the analyses that used the black spot comparison group ($t = 12.697$; df = 133; $p < 0.001$) and for the analyses that used the crash frequencies in Flanders ($t = 18.747$; df = 133; $p < 0.001$). Next to the crash level, also a favourable effect was found on the casualty level for each of the road user categories (car occupants, moped riders, cyclists, motorcyclists, pedestrians and truck drivers).

An analysis of the characteristics of the locations showed five significant parameters. At first significant differences were found according to the type of treatment. The highest effects were found for priority controlled intersections with changes in the layout (−42%) or at which traffic signals were installed (−35%). The priority controlled intersections with changes in the layout performed significantly better compared to signalized intersections at which left-turn protection signals were implemented (−22%) and performed significantly better compared to signalized intersections with changes in the layout (−11%). The conversion to roundabouts of both previously priority controlled and signalized intersections leaded to a decrease of 21% in the number of injury crashes. These results are different with the results that were found in a recent and extensive effect evaluation study of 1599 black spots in Australia. This study found the highest effects for roundabouts, which showed a decrease of 71% in the number of injury crashes (BITRE, 2012). A meta-analysis of Elvik et al. (2009) of several studies that analyzed the effect of the conversion of intersections to roundabouts, also found highly favourable effects, with a decrease in the number of injury crashes of 46%. A study of 55 intersections that were converted to roundabouts in different states in North-America showed a decrease in the number of injury crashes of 76% (Rodegerdts et al., 2007). The result in the present study was however more limited for this treatment. Furthermore, the Australian study found that new signals, especially during the day, and altering the traffic flow direction were the next most highly effective treatments. The study found a decrease of 51% in the number of injury crashes during the day and 36% during the night, after the installation of traffic signals. A study of 100 four-leg intersections in North-America showed a more limited result, with a decrease of 23% in the number of injury crashes. A distinction according to the crash type showed a decrease of 67% in the number of right-angle crashes but an increase of 38% in the number of rear-end crashes (McGee et al., 2003). A meta-analysis of Elvik et al. (2009) resulted in a decrease of 15% in the number of injury crashes at three-leg junctions and −30% at four-leg intersections. The intersections in the present study, from which the majority (84% of the treated locations) were four-leg intersections, showed similar effects (−35%) after the installation of traffic signals. It is however difficult to compare the results of the best performing treatment in the present study with previous studies, as the changes in the layout of priority controlled intersections comprised different treatments (e.g. provision of cycle facilities, improved delineation and construction of traffic islands or medians). Nevertheless it can be concluded that in the Flemish black spot programme the adaptation of intersections that were priority controlled before the treatment performed better than locations that were signalized. A possible explanation

for the higher results for priority controlled intersections is that these locations can undergo different changes in order to control the traffic flows. Such measures can be expected to have a strong effect on traffic safety. As signalized intersections are already highly controlled, possible changes are limited, and will subsequently be less effective.

Furthermore, also the priority score was found to be a significant parameter. The present study showed that the higher the priority score (i.e. spots were more dangerous during the before period) the higher the effects on the number of injury crashes. This result indicates that particularly the most severe locations profited from the black spot programme. The last parameter that was found to be a significant predictor is the traffic volume, and lower effects were found with higher traffic volumes. This result can be explained by the selection procedure of the black spots, which is based on the number and severity of injuries. Previous research showed that the traffic volume is the most influencing structural variable for the number of crashes at a certain location (Elvik et al., 2009). As traffic volumes were not taken into account during this selection, an actual chance exist that locations with a high volume were selected because of the high crash frequency as a result of this high intensity. At the intersections with a high crash count but with a lower volume, probably other structural factors could have had an effect, which could be managed more easily through infrastructural measures.

8. Conclusions

As a result of the black spot management, a significant and substantial decrease in the number of crashes was found. This decrease was higher for the severe crashes (46–57%) compared to all injury crashes (24–27%). The highest effects were found for priority controlled intersections with changes in the layout (−42%) and at which new traffic signals were installed (−35%). On the level of casualties, a decrease was found for every road user category.

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